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Designing Tangible User Interfaces to Support Participation
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report of a PDC 2002 workshop

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Overview

Introduction

Tangible User Interfaces are of increasing interest in research and are beginning to show their potential for practical applications. Due to the differences from Virtual Reality systems and traditional WIMP interaction via monitor, mouse and keyboard, established design knowledge from these areas often does not transfer onto tangible interfaces. Hardware and software need to be designed as a well-integrated unit, necessitating more than just graphics, colourful icons, and clear navigation. Interaction with a tangible interface includes the physical, graspable look and feel, issues of parallelism in the interface, and what representational characteristics are used. Thus in addition to the challenge of the lack of standard design solutions and patterns, many entirely new design issues need to be explored. In addition, tangible interfaces show great potential for supporting collaborative situations (e.g. in participatory design), necessitating a different approach to design itself. These aspects affect both the resulting design (in terms of design recommendations and in terms of “good“ design examples) and the process of design (user participation, assessment and evaluation of systems).

The number and types of systems relating to tangible interfaces is continually growing. What we are still missing is more general, encompassing knowledge about the specific design issues surrounding them. Tangible interaction remains one out of numerous issues in HCI and Augmented Reality conferences. As far as we know, the ACM DARE conference (Designing Augmented Reality Environments) in 2000 has been the only bigger event bringing together researchers from this field. The organisers of this workshop were motivated by the growing interest in and the need for a focused discussion of tangible interaction. Incidentally, a few days later another workshop on tangible interaction took place at DIS`2002 in London, organised by Tom Djajadiningrat, Jacob Buur, and Margot Brereton (Djajadiningrat et al 2002).

The title of the workshop can be read as pointing to three sub-topics:
1) **Designing** 2) **Tangible User Interfaces** to 3) Support **Participation**
Not mentioned within the title, but equally important are the support of creative processes & innovative thinking.

The workshop had several aims: generating dialog among those involved in developing hardware and software for tangible user interfaces, those involved in applying technology to collaborative processes, and those engaged in assessing the usability and efficacy of such environments; giving people the chance to experience tangible interfaces in hands-on exercises; bringing together existing design knowledge and experience; and discussing the specifics of tangible interaction, especially concerning group use. To focus discussion, the workshop was introduced with the following questions:

- What do we consider to be a good tangible interface? (quality criteria)
- In which kind of work processes and activities do we prefer tangible interfaces over “ordinary“ interfaces? (application areas)
- How should the design process for collaborative tangible interfaces look?
- How can the design of these interfaces be assessed (their efficacy and usability) ?
- What specific problems of collaborative work processes are important to address in design?

We were not able to address all of these questions in the 3-hour timeframe of the workshop, and instead focused on design issues rather than including the design process questions. The unanticipated high number of participants, while demonstrating the considerable interest in the topic, contributed to the time constraints. In spite of this, we discussed some of these questions in sub-groups, gathered and summarized the results. Many different perspectives and approaches were introduced by the participants, often pointing to new issues or offering challenging opinions. As several people commented, each of these questions would be worth an entire follow-up workshop.

Program of the workshop

2:00 Welcome and Introduction
Participants introductory round, ”grab in the bag“ sensing experiment
2:45 Hands-on experiences:
- PitA-Board scenario & role-play, Tangible Viewpoints, Generic Tag & Track Table)
3:30 Splitting into 3 sub-groups, reflecting on hands-on experience, discussion
4:15 Reconvene, summary of sub-group discussion,
Lone, Hal, Eva: short perspective statements on tangible interfaces,
continuation of discussion, focusing on remaining issues on flip-overs
5:00 End of workshop

The participants during hands-on experiences

The workshop started with a short introduction, explaining the aim and program of the workshop and giving some background of the three organisers. After this a longer time slot was allocated to an introductory round for the participants. We asked people to tell their names, to explain their connection to and/or research experience with tangible interfaces, and to tell the group what they hoped to take home from this workshop, any existing questions and hypothesis concerning tangible interfaces, and what they believe to be design issues.

The introductory round was coupled with a ”sensing experiment“. Each participant was given a closed plastic bag after introducing him/herself, asked to put his/her hand inside and to describe what (s)he felt. Inside the bags various objects of diverse materials with interesting texture, form, and tactile quality had been placed. This experiment had been used before in a student seminar on Virtual and Augmented Reality by Eva Hornecker, where it had been successful in making participants realise the sensory richness of their hands and the many dimensions of tactile interaction. For the workshop the exercise met the goal of highlighting the richness of our sense of touch and its aesthetic and emotional aspects.

Due to the long introductory round (with 24 people) the hands-on experience could not have the full hour planned for. The group was given time for an introduction to each of the three systems and to interact with it, one system after the other. Unfortunately, because of the large group size, not all participants had a chance to put hands on the systems. As all of the system owners wanted to experience the other systems as well, it was not possible to introduce all systems in parallel. In the following a short summary of these systems is given.

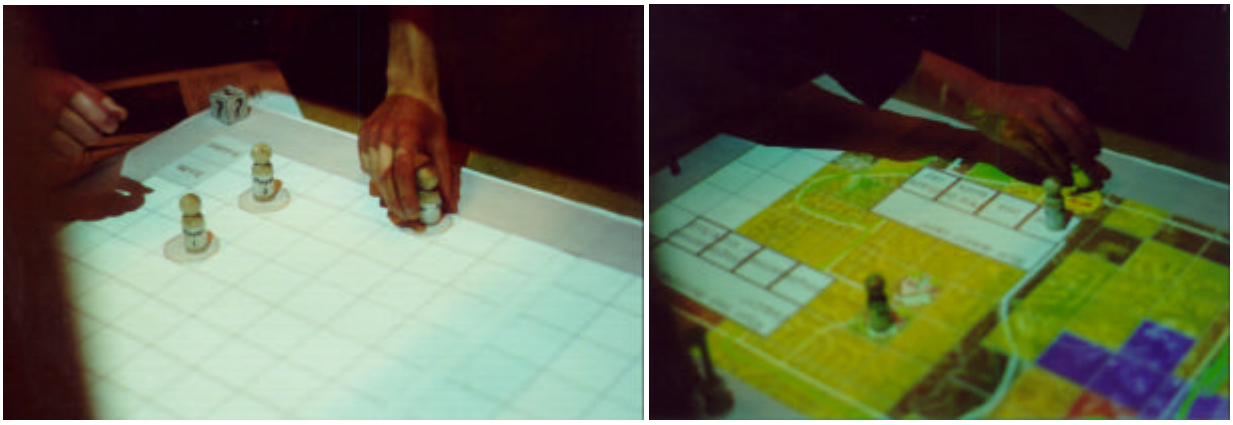
The group was then split into sub-groups of approximately six persons each. The sub-groups met after a short break, taking the chance to enjoy the sunny weather outside. The groups had been given some questions to direct the discussion: How did you like the systems? What was good? What could be improved? How did it feel to interact with it, how did it effect group interaction? What about aesthetics and embodied interaction?

When the groups met again, they were asked to give a summary of the discussion. The three workshop organisers then each gave a short position statement, focusing on their approach to tangible interaction and their research questions. The rest of the workshop focused on remaining open questions and deepening some issues.

The systems shown

The *PitA-Board* was briefly introduced by Hal Eden. He also presented a use scenario that described the inhabitants of a neighbourhood being asked to collaborate in making a proposal for an improved bus route through their neighbourhood. The system consists of a white, gridded board, showing the neighbourhood and a top-down projection. Volunteers were recruited for the role-play and were given the tangible tokens and role-sheets, describing the personas they were to play. The tokens were made from wood, resembling large-sized board-game person figurines. In addition, there were bus stops, a wooden vehicle for creating busses, and several square tokens for various functions (drawing bus route, deleting, questioning). The system senses the tokens, when placed on the gridded squares of the board. The remaining participants were watching the interaction. Portions of the role-play scenario were played through, short-cutting at several points in order to give participants an overview of the interaction possibilities and features of the system. For more information on the system see: (Arias et al 1997, Hornecker, Eden, Scharff, 2002, and Eden, Hornecker, Scharff, 2002).

The participants starting with the role-play on the PitA-Board, reading persona descriptions and during interaction



The PitA-Board: introductory phase (experimental use of tokens) and during the scenario

Then Ali Mazalek introduced the *Tangible Viewpoints* system, which was part of the interactive art exhibits at PDC. Tangible Viewpoints explores tangible, interactive storytelling. A group of high school students had created the content, telling about their lives. The system consists of a frosted glass board and a top-down projection plus a separate vertical monitor. Each tangible figurine representing one of the students was a large-sized board-game piece made of frosted glass with a coloured bottom, and was surrounded by projected bubbles with images corresponding to audio and video snippets related to the students. Each figurine had a sort of coloured aura surrounding it: Putting two figurines closer to each other had the effect of combining auras, making visible only those snippets relevant to both students. A small glass pebble was used to select the projected image bubbles, causing the corresponding snippet play on a separate monitor. The story proceeds in reaction to those snippets already played. More information on this system can be found in Ali's PDC paper (Mazalek et al, 2002) and on her website (http://web.media.mit.edu/~mazalek/projects/tvpts/).

Ali demoing the Tangible Viewpoints

The *Generic Tag & Track Table (T3)* was introduced by student Micke Rundberg and Lone Malmborg, both from K3, Malmö. They demonstrated an application aimed at supporting collaborative sketching among designers in which paper sketches are digitised (scanned) and marked with coloured tags. A video camera inside the T3 recognises these coloured tag patterns and can identify sketches put onto the table surface and their position and orientation. The table itself offers a big white surface, on which paper sketches can be

shuffled and organised. A separate monitor reflects this activity, interpreting the organisation of paper sketches visually. The resulting images serve as inspirational material, enabling designers to shuffle sketches experimentally and exploratory.

Lone and Micke explaining about the Tag and Track Table

Organisers perspective statements

Eva Hornecker:
My research is part of my PhD thesis on tangible interfaces and cooperation, especially on the design issues that result from cooperative use. Most research on tangible interfaces consists of developing new systems, thus pushing further our knowledge about possible application areas, technical feasibility and application-oriented design issues. Part of my research consists of collecting, summarising and condensing this distributed knowledge, trying to extract more general issues. Tangible interfaces differ from traditional interfaces in many issues, posing completely new design possibilities and problems. For example computer scientists have only learned to design software and graphical interfaces. But with tangible interfaces we need an integrated design of the material interface *and* the digital parts, we are challenged with representational issues as well as with sensing technology issues. One thing that fascinates me, is that tangible interfaces allow for bodily interaction, that they include all of our senses. We are trying to regain a part of life that has been diminished by existing technology. The bodily interaction with tangible interfaces appeals to many people, both technology people and non-technologists.

There seems to exist a shared impression that tangible interfaces lend themselves to cooperative use situation. Many systems explicitly are supposed to support collaborative use, especially in the area of design. Yet there has been barely any research focusing on this. Evaluation of tangible interfaces up to now only looked at single-user interaction, even if these systems were aimed at collaborative use. Yet we know from CSCW that single-user usability requirements can contradict group requirements, or that single-user requirements get unimportant in the group use situation. If we want to support collaborative situations, we should focus on this. So first we need to understand the specifics of collaborative use, the interaction patterns. And we need to know what it is in tangible interfaces that makes collaborative usage of them so productive and enjoyable. Knowing this, we could design much more explicitly for collaboration and knowingly exploit these properties.

Last year I cooperated with researchers from the Center of LifeLong Learning and Design in Boulder during a research visit on the assessment of two systems, using a group role-play. The role-play allowed us to observe a kind of simulated collaborative use situation, having people from outside of computing use the system in a quasi-realistic situation and give us feedback. One of these systems will be presented later on here.

Hal Eden
The PitA-Board demonstrated at this workshop represents the current state of a research agenda for supporting citizen participation in design that reaches back to 1994. It is part of the Envisionment and Discovery Collaboratory (EDC) project at the Center for LifeLong Learning & Design.

The roots of this project are found in the work of our colleague, Dr. Ernesto Arias, in the College of Architecture and Planning at the University of Colorado at Boulder. Using physical models representing neighbourhoods, he worked with residents of the Cole Neighbourhood in Denver, Colorado, to understand the nature of the problems they faced and to collectively determine how funds that had been made available through grants and loans would best serve neighbourhood revitalization.

Our collaboration has led to an effort to understand how integrating the tangible and tactile nature of these physical models, the direct affordances of face-to-face interaction, and virtual design environments can support community-based design activities.
As a computer scientist and HCI researcher, I am certainly interested in advances in technology and new paradigms for interaction, but the major thrust of my work in on understanding how these embodied design environments can be applied to design and citizen participation, utilizing meta-design principles to support learning and informed participation as new forms of social creativity.

Lone Malmborg
During the last 7-8 years I have had a strong interest in new ways of interacting with computers. Most of this work has been based on the idea of using more senses in the interaction. While starting out with doing VR-based interfaces (Malmborg, 1996), I tend to believe in ubiquitous computing today, meaning that the computer disappears into the space around us and allows use to move freely while still being augmented in different types of activities.
I believe that there exist a strong and close relation between humans' cognitive abilities and the possibility of using multiple senses including the kinaesthetic sense (Kirkeby and Malmborg, 1996). Tangible interfaces can be considered a specific type of kinaesthetic interface, though most tangible interfaces for collaboration are quite limited in use of the kinaesthetic sense. In the examples at the workshop objects are moved primarily by using just hand-/arm-manipulation to change position of the objects, but in e.g. the PiTa-board use-situation collaboration also takes place by actors changing their position physically around the table. Important for me in this context is to stress that cognitive abilities are closely coupled to embodied experiences, which also includes moving objects around by using hand-/arm-manipulation and not only 'full' kinaesthetic movements. Probably this coupling between cognitive abilities and embodied experiences holds especially for learning activities. Many authors have stressed the connection between learning and the possibility of touching and moving objects. An early but influential representative for this idea was Jean Piaget (1972) who provided an epistemological foundation for the educational idea of letting manipulative material play a central role in learning. Piaget suggested that children must first construct knowledge through 'concrete operations' before moving on to 'formal operations'. More recent advocates for this idea are Sherry Turkle and Seymour Papert (in Resnick, 1996), who want to re-valuate the concrete, suggesting that 'abstract reasoning' should not be viewed as more advanced than concrete manipulations.

Currently Mitchel Resnick and his group at MIT Media Lab are among the most important sources for innovative concepts and developments in this field by coining the concept 'digital manipulatives' and designing a row of tangible user interface prototypes based on this concept.

The idea of using a kinesthetic approach to interaction design is also suggested by Svanæs (1997). He refers to Johnson (1987) who proposes ‘kinaesthetic image schemata’ to describe experiential wholes resulting from interaction with our physical environment. Svanæs uses the term ‘kinaesthetic thinking’ to signify direct cognitive operations on tactile-kinesthetic sense experiences. Further, Svanæs draws interesting parallels to dancers and their use of body movements .

I believe that the idea of a synkineasthetic approach is highly relevant in design of computer-supported learning environments. The importance of a synkineasthetic approach in human cognition is also supported by Lakoff (1987), who reports on psychological experiments where blind subjects perform mental operations on tactile pictures: “It seems to me that the appropriate conclusion to draw from these experiments is that much of mental imagery is kinaesthetic - that is, it is independent of sensory modality and concerns awareness of many aspects of functioning in space: orientation, motion, balance, shape judgment, etc.” (Lakoff 1987, p. 446).

Synkinesthetic interaction is to a large extent ‘tacit’ in the sense that it is not simply the manipulation of symbolic representations. Creation and expression of meaning is embedded in body movements. Using Polyani (1966), synkineasthetic interaction is a way to perform ‘tacit knowledge’ in a learning situation.

Results and discussion issues of the workshop

Participants and their initial introductory statements

The mix of participants was very heterogeneous, representing diverse backgrounds. Some had a lot of previous experience in research on tangible interfaces, others had none and wanted to find out what they are. Those who indicated their expectations wanted to take home new examples of tangible interfaces, to come up with ideas, find out about design options, and draw inspiration from the presented work. ..

Several participants were Interaction Design students or researchers at K3 and elsewhere, some were computer scientists, many came from HCI backgrounds or user-centered design, others from industrial design, architecture, or cognitive science. In addition there were several artists working on tangible systems (e.g. for storytelling and children's play) and from film and media studies. Three or more of the participants were working for Danfoss in user-centered design, one was an interaction designer at Sony-Ericsson, another was working at the Mixed Augmented Reality Center at Lund University, which offers a full scale lab for architects. One person with a film and media background mentioned that he is normally doing the opposite of tangible interaction: "Creating an unreal world and make people feel it's real."

Some saw connections with tangible interaction from their own work e.g. with Rapid Prototyping (as enabling tangible interaction with prospective systems and objects), the use of tangible media or models for exploring designs in architecture, one person interpreted mobile devices as a form of tangible interaction, another was working on tangible manuals, whereas another participant reflected on the tangible quality of inspirational material in design processes,

Hypotheses and opinions based on participants' experience (from the introductory round)

The impression that *support of collaboration* is a strength of tangible interfaces was shared by many participants and mentioned by at least 8 people explicitly. This was mostly in connection to the use of *tangible models or media in design processes*. For example, an experience from the area of Rapid Prototyping in design was that "Physicality can produce shared meaning" and that it makes exploring and sharing of project ideas possible. It was proposed to "use a TUI to create meaning and then shift to digital interfaces." Co-operation between people from different backgrounds (e.g. architects and interaction designers) and between project members was mentioned several times in this context.

Some participants stressed *tangibility, embodiment and everyday-world interaction*: Tangible interfaces can offer a holistic experience of interaction, can utilise various kinds of sensory inputs and outputs, giving e.g. "feedback through your hands". Everyday objects are tangible, so we should look at how people experience their everyday life. "Action and physical things are part of cognition." Properties of physical artefacts are therefore an important design issue.

Other participants asked to "*explore how we can interact with computers in a new way*." On the one hand interaction with technology should be cognitively similar to everyday interaction: "Using things should be as easy as walking through a door." It should be "*fun to use things", interaction should be intuitive, natural,* and haptic. On the other hand, *technical*

possibilities and functionalities were emphasised, e.g. “devices that talk to each other“ or that tangible interfaces could take advantage from information related to the context of use. Feedback from digital systems can be given in a tangible, material way.

The sensing experiment

The exercise of reaching into bags with unknown content enlivened the introductory round, producing comical situations. Participants got very curious about the content. It was interesting to observe their faces. Most seemed to concentrate intently, and appeared a bit tense and anxious when starting to reach inside. Their reaction to touching the content ranged from smiling, to surprise, puzzlement, or even concern if the content felt uncomfortable.

Many tried to analyse the form of things and to discern the object, instead of only describing the sensory impression and the tactile qualities. Even though this was not according to the organisers’ intention, it was interesting how some objects were recognised quickly (e.g. sugar-cubes and curlers). This is a strong indication of the perceptual intelligence of our hands.

Some example comments of people when feeling inside the bags

- *potato flour:* "What is this - it has no weight, no resistance---it feels soft, liquid, fluent, but it is not wet. Very strange."
- *A net for dishwashing:* "this is qualitative. It is soft, tight-structured"
- *mustard seeds:* "this feels great--very pleasing, I could go on for hours!" (smiling)
- *Dried flowers:* "What is this, it feels dirty, scratchy" (makes an uncomfortable face)

The exercise met the intention of making participants conscious of their sense of touch and its richness. Some commented during the sub-group discussion that they liked the exercise, that it effected their mood, made them realise the aesthetic and emotional aspects of touch.

Discussion summary

We recorded some issues for discussion on flipcharts and tried to add topics and comments to the appropriate flipchart during discussion and the sub-group presentation. As there was not enough time to deeply discuss these issues, the results resemble a brain-storming of topics that need deeper exploration than a complete discussion of the issues. The issue of assessment or evaluation of tangible interfaces was not touched during discussion. The following presentation of results consists of the flip-over notes (grammatically corrected) along with some explanatory comments for each item.

'Quality' criteria – what are 'good' tangible interfaces

- clear affordances
- physical design
- reduce complexity of real world
- directness (of interaction)
- informal interface
- intuitiveness
- not a computer (style / aesthetics)
- natural movement
- some resistance / surprise

Quality criteria were a focus of discussion, as there was no consensus on all of the collected ideas. Which criteria apply seems to depend on the concrete system, application area and use situation. There was more or less agreement that a good tangible interface should have clear and easily recognisable affordances, The physical design of tangible interfaces is a design issue in itself (different from normal systems, which just use the monitor as an generic display surface).

While making computer interaction as natural and intuitive as interaction in the everyday world, tangible interfaces should reduce the complexity of the real world (and not mimic or reproduce it). Interaction should be direct and as unmediated as possible. The natural movement of users in physical space should be supported; it should even be part of the interaction. If systems are huge and one uses the whole body, the technology might seem to disappear.

Some participants stressed that tangible interfaces should not look like a computer and follow a different style and aesthetics. They preferred systems that looked more rough, low-cost and less shiny (rather than, for example, glass or polished metal), giving users the impression that they are allowed "to mess around". The system should make visible "what it is about—not computers." In these effects the presented systems had been very different. While the drag-and-drop table was mentioned as looking very rough and low-cost, the Tangible Viewpoints was felt as looking high-tech, shiny and following a computer-aesthetics, while the PitA-Board was felt as being somewhere in the middle with its game-board like aesthetics. Other participants especially liked the aesthetics of the Tangible Viewpoints systems (nice touch and feel, the clips clinging to figurines) and did not consider it to be "like a computer". What feels like a computer may depend greatly on users background and personal aesthetic preferences.

Another idea was that systems should also offer some surprise or resistance to users, instead of always acting according to expectations. This could create curiosity and foster exploration and learning.

Collaborative use aspects

- how can computer understand multiple user use
- swap between individual and multiple user view
- 6 dialogue boxes in parallel → new design issues
- social negotiation of interaction
- control vs. democracy → share control of representation

The list of design issues regarding collaborative use noticed by the participants may seem short at first sight, but points to many new and difficult design problems and technical problems. How can a computer distinct multiple users interacting in parallel and understand this? A problem was seen in the fact that a tangible interfaces presents one representation to everybody present. It should be possible to swap between different views.

The PitA-Board with its use of menus for making choices led to the observation that with several people interacting in parallel with these menus, one could end up with six open dialogue boxes in parallel. How to distribute these in space, how to orient them (legibility), how to avoid cluttering of the interaction space are design problems which never existed in single user interfaces.

Other participants noted that some of these problems might not be that important in practice. By social negotiation of interaction, user groups (especially when co-present) would, for example, avoid over-cluttering space, negotiate access of objects, or help each other in deciphering upside-down text. For access control, two opposing models exist: control versus democracy. Social negotiation of access would amount to shared control over representations.

Where do we prefer tangible interfaces to traditional ones? (areas, activities ...)

- everyday environment
- where people need to see what others do (learning, imitation, modelling) awareness
- entertainment (amplifying experience)
- where we already have functioning, good artefacts
- easy access, not training
- fit with application area
- multi-modal feedback (control rooms)
- functions that need to be very intuitive and automatic

The group managed to brainstorm an impressive list of areas or activities where they believed tangible interfaces to be superior to traditional ones. If there exists an everyday environment, tangible interfaces were felt as a natural addition. If there are already good functioning artefacts, these should be augmented (thus resulting in tangible or augmented interfaces) instead of replacing them with purely digital technology.

Where there is a need for people to see what others are doing, in order to learn (imitate, follow a model) or to heighten awareness of events, tangible interfaces should be preferred, as they convert system interaction into bodily, visible actions and invite collaborative interaction and over-seeing of activities. Tangible interfaces were seen as superior were there is a need for easy, immediate access to systems and no training of users possible.

A big application area was seen in the field of entertainment, where tangible interfaces could amplify the interaction experience. The interface should fit with the application area, making it necessary to ask anew for every application which kind of interface should be preferred. Another huge application area was seen were multi-modal feedback is needed (control rooms are an example) and where users operations must be done very intuitive and automatic.

Body interaction & aesthetics

- aesthetics are important
- whole body
- body <-> thought
- invited to grab and interact
- standing around allows more body movement
- how much place for one person
- share same way
- physical interaction

All participants felt that aesthetics are important in tangible interface design. As noted above, aesthetic preferences differed individually. Many noted that all of the presented systems enabled using the whole body in interaction (walking around, changing viewpoint, using body language while manipulating the system). A connection between the body and the process of thinking was seen (for example some people like to think while walking, some cannot talk without using their hands).

Some people noted that standing around the systems allows more body movement as sitting. Standing and the size of systems also enabled more people to observe them. Yet the group had been too big for good visibility. Thus the size of interfaces in combination with the space needed for one person each limits the group size.

The systems made people feel ”invited to grab and interact“. This was noted as especially interesting and different to screen-based interfaces with mouse-interaction only. The easy availability of tangible tokens, their parallel accessibility and the game-character of interaction may contribute to this impression. All participants share one representation and share interaction methods with the system, a fact that may contribute to creating sharing and collaborating.

Design issues

- digital <-> physical (extending)
- how to get the right response
- allow for single user phases
- intuitiveness
- exploiting affordances
- move beyond flat surfaces
- low-tech / rough interfaces nice! -> make it feel less like computer
- trade-off overview – space for movement
- allows for not programmed behaviour of users.

Some design issues that follow from the other flip-overs were not explicitly repeated . Design issues were seen, for example, in the coupling of digital and physical representations and the extension (or augmentation) of physical objects. Intuitiveness and the exploitation of affordances which invite users to perform certain actions were mentioned very often.

Allowing for single-user phases, e.g. for making individual notes or testing an idea privately was also considered important for a tangible interface. Participants noted that all presented systems had been table-based, using flat surfaces only. Moving beyond flat surfaces, which would make new application areas possible and broaden interaction possibilities was viewed as critical. Systems should also allow for interaction behaviour of users that was not explicitly anticipated, supporting adaptation and ad-hoc creation.

Once again there was a strong mandate to make systems feel less like computers by using low-tech interfaces. The size of interfaces was noted as either posing a dilemma or a trade-off between offering an overview and providing space for movement. If an interface gets too large, overview is lost and accessibility becomes difficult. When many people want to observe or interact with the system, they need to get close together in order to have an overview, while losing space for movement.

The following website contains annotated web-links to online resources (only websites, not other documents online) on tangible interfaces. Eva Hornecker is collecting websites of tangible interfaces and related systems or other research relating to tangible interaction. Please e-mail her about any web resources you find to be missing.

http://www.artec.uni-bremen.de/people/Eva/Tangibles.html

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